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AIRCRAFT RESEARCH AND DEVELOPMENT UNIT

(9) ENGINEERING REPORT

APPROVED

FOR PUBLIC RELEASE

(6) DEVELOPMENT OF AN INSTRUMENT FOR THE ACCURATE MEASUREMENT OF AIRCRAFT AIRSPEED AND ALTITUDE

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Aircraft Research and Development Unit has developed a trailing pitot-static probe suitable for determining pressure error corrections for aircraft airspeed and altitude systems. The instrument is suitable for use with helicopters where both pitot and static pressure measurements on the aircraft could be subject to pressure errors due to rotor downwash. The probe is accurate to better than 1% and was tested and shown to be satisfactory over a speed range of 40 to 120 knots.

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AIRCRAFT RESEARCH AND DEVELOPMENT UNIT

DEVELOPMENT OF AN INSTRUMENT FOR THE ACCURATE MEASUREMENT OF AIRCRAFT AIRSPEED AND ALTITUDE

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AIRCRAFT RESEARCH AND DEVELOPMENT UNIT

TECHNICAL INVESTIGATION NO 466

DEVELOPMENT OF AN INSTRUMENT FOR THE ACCURATE MEASUREMENT OF AIRCRAFT AIRSPEED AND ALTITUDE

SUMMARY

Aircraft Research and Development Unit has developed a trailing pitot-static probe suitable for determining pressure error corrections for aircraft airspeed and altitude systems. The instrument is suitable for use with helicopters where both pitot and static pressure measurements on the aircraft could be subject to pressure errors due to rotor downwash. The probe is accurate to better than 1% and was tested and shown to be satisfactory over a speed range of 40 to 120 knots.

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DEVELOPMENT OF AN INSTRUMENT FOR THE ACCURATE MEASUREMENT OF AIRCRAFT SPEED AND ALTITUDE

INTRODUCTION

1. Reference A tasked Aircraft Research and Development Unit (ARDU) to develop an instrument for the accurate measurement of aircraft airspeed and altitude. The requirement arose primarily from the need to determine pressure errors for rotory winged aircraft where both the pitot and static pressure sources could be influenced by the main rotar downwash. The task required ARDU to:

a. design and manufacture an accurate instrument for the measurement of rotary wing aircraft airspeed and altitude pressure errors;

b. calibrate the instrument, and

c. conduct flight tests to ensure that the instrument was stable in flight.

2. Two basic designs of trailing pitot-static probes were manufactured and flight tested. The first, based on an Aeronautical Research Laboratory (ARL) designed trailing static probe was abandoned after the first flight test which showed the flight characteristics were unsatisfactory and it was felt that this design had little chance of successful development. The second design, based on a U.S. Naval Air Test Centre design, was manufactured and test flown and, although not satisfactory in its initial form, showed potential. This design was further developed to produce a satisfactory trailing pitot-static probe.

TRAILING PITOT-STATIC PROBE DESIGNS

3. Design 1 (Modified ARL Design). An ARL trailing static probe was modified to include a pitot pressure hole in the nose of the probe. Pitot pressure and static pressure were transmitted through separate plastic tubes and the probe was suspended from the aircraft on a steel wire. The probe is shown in Annex A. It weighed 5.5 lb (2.5 kg) and was 29 inches (73.7 cm) long.

4. Design 2 (U.S. Naval Air Test Centre Design). This trailing pitot-static probe, shown in Annex B, was manufactured at ARDU to a drawing (No E1103) from the Technical Support Division Design Section, U.S. Naval Air Test Centre, Patuxent River. However, to place the centre of gravity (CG) in front of the support system, a 6.25 inch (15.9 cm) brass extension was added in front of the suspension point and this was incorporated in Design 2 shown in Annex B. The probe was 39.5 inches (100.3 cm) overall length and was constructed primarily of brass tube of 1.5 inch (3.8 cm) outside diameter with a solid brass hemispherical nose. The aluminium perforated tail cone was 12 inches (30.5 cm) in diameter. The suspension system consisted of an aluminium collar and pivoting stirrup. The all-up-weight of the probe was 13.5 lb (6.12 kg). The probe was supported by a 2,000 lb steel cable of 3/16 inch (5 mm) diameter and the pitot and static pressures were transmitted through 5/16 inch (7.9 mm) outside diameter plastic tubing. The plastic tubing was held to the steel cable with spiral plastic binding (Spirap). The suspension wire, plastic tubing and Spirap weighed 0.13 lb/ft (0.193 kg/m).

5. Design 3 ARDU Trailing Pitot-Static Probe. Further development of Design 2 was carried out to overcome the shortcomings in the calibration (Paragraph 9) and in the flight characteristics (Paragraph 7) and this resulted in the Design 3 trailing pitot-static probe shown in Annex C. The major changes between Designs 2 and 3 were an increase in the length of the probe by 10.5 inches (26.7 cm) between the suspension point and the tail cone and an increase in weight by lead ballasts, redesign of the connection of the steel cable to the probe, allowing the deletion of the collar and stirrup, and the use of lighter steel cable and plastic tubing. As a result, the Design 3 probe was 50 inches (127 cm) in length and weighed 14.5 lb (6.58 kg) and the weight of the 3/32 inch (2.4 mm) diameter suspension cable and tubing (3 mm I.D.) was reduced to 0.053 lb/ft (0.079 kg/m).

TESTS MADE AND RESULTS

Flight Test of Design 1

6. This design proved unsatisfactory because, at speeds in excess of 30 KIAS, the probe pitched and yawed wildly. The stability criterion given in Annex D indicated speeds up to 45 KIAS may be achievable but that a total redesign would be necessary to achieve a useful towing speed of 100 KIAS. For this reason, Design 1 was abandoned and no tunnel calibration of the instrument was undertaken.

Flight Test of Design 2

7. Design 2 trailing pitot-static probe was test flown from Iroquois helicopter A2-390 with a 150 foot length of cable (i.e. greater than twice rotor diameter Up to about 80 KIAS, the probe was marginally stable, oscillating in pitch and yaw up to $\pm$ 6°. At speeds above 80 KIAS, the oscillation started to diverge. This is somewhat higher than the speed predicted by the stability criterion given in Annex D. The flight characteristics were considered unsatisfactory. The probe was flown from Nomad A18-303 with generally similar results.

8. Examination of film records from a chase aircraft indicated that, in addition to the probe being disturbed by cable oscillations, the probe itself was not particularly stable.

9. Calibration of Design 2. Design 2 was originally calibrated at ARL but the probe was subsequently shown to have severe air leak problems in the plumbing so the calibration was disregarded. A subsequent calibration was carried out at Weapons Systems Research Laboratories (WSRL) with the internal plumbing modified to cure the leak problem. This calibration showed that, at zero angle of attack, the probe had a pressure error which was a function of the angle between the stirrup and the axis of the probe. As this angle varied with the towing speed, the calibration for use in flight tests would depend on calculated corrections for this angle which would degrade the confidence in the calibration accuracy. The error for this probe was as much as 2 KIAS at 100 KIAS.

Flight Test of Design 3

10. Design 3 trailing pitot-static probe was test flown on a 150 ft cable from Iroquois A2-390. Tests were carried out at 70 KIAS and 110 KIAS straight and level, 110 KIAS at 1,000 ft/minute rate of descent and 80 KIAS at 500 ft/minute rate of climb. Under all conditions tested, the probe was stable and response to atmospheric disturbance was well damped. The suspension cable and

associated plastic tubes were reasonably stable and the only oscillatory motion noticed was about two thirds of the way between the aircraft and the probe, where the cable had a local oscillation of about $\pm$ 1 ft. The cable was fixed to a mounting point on the floor of the helicopter with the cable passing out the door and sliding along the side of the skid. The towing cable stayed well clear of the tail rotor and it was estimated that the minimum distance between cable and tail rotor was approximately 10 ft (3 m). During all the flight tests with the probe, the helicopter crewman carried bolt cutters and sat where he could watch the cable to tail rotor separation. He was in a position to cut the cable if there was any risk of the cable fouling the tail rotor.

11. Calibration of Design 3. ARL calibration data is given in Annex E together with the ARL calibration data for a second Design 3 trailing pitot-static probe manufactured by ARL to ARDU drawing No 78015000 (Annex C). The pressure error correction (PEC) to be used with the Design 3 trailing pitot-static probe is given in Figures 4 and 5 of Annex E.

Time Lag Associated with Design 3 Probe and Instruments

12. Time lags in the response of standard aircraft instruments connected to the probe through 150 ft lengths of 3 mm I.D. plastic tube were as follows

a. With an airspeed indicator (ASI) and an altimeter connected, the static ports on the probe were evacuated until the ASI read 150 KIAS and the altimeter read 1,000 ft. When the static ports were vented to atmosphere, it took approximately 15 seconds for both instrument readings to fall to zero.

b. With only the ASI connected to the probe, the IAS took approximately four seconds to fall from 150 KIAS to zero using a similar test to a. above.

From this it is clear that, with an ASI and altimeter connected to the probe, it is suitable only for steady state measurements and would require 15 seconds to settle. With only an ASI connected to the probe, a settling time of four seconds is required and could be used for slowly varying conditions. However, care is needed in assessing the significance of lag effects and, if account of these effects is required, the system lags would have to be determined more accurately.

Use of Design 3 Trailing Pitot-Static Probe

13. The probe has been used to determine PECs on the CT4 Airtrainer (Reference C) and on the Nomad (Reference D). The CT4 was flown in formation with an Iroquois helicopter carrying the probe. For the Nomad, the probe was flown from the hatch of the test aircraft.

CONCULSIONS

14. ARDU has developed a trailing pitot-static probe suitable for use with rotary- or fixed-wing aircraft. The probe was proven to be stable from 40 to 120 KIAS and wind tunnel calibration showed that its PEC is less than 1%. An accurate calibration of the probe is given in Annex E, Figures 4 and 5.

REFERENCES

A. HQSC 3000/7/1-466(5), 19 November 1974

B. NACA TECH NOTE 1796, Theoretical Analysis of Oscillations of Towed Cable by William H. Phillips, January 1948

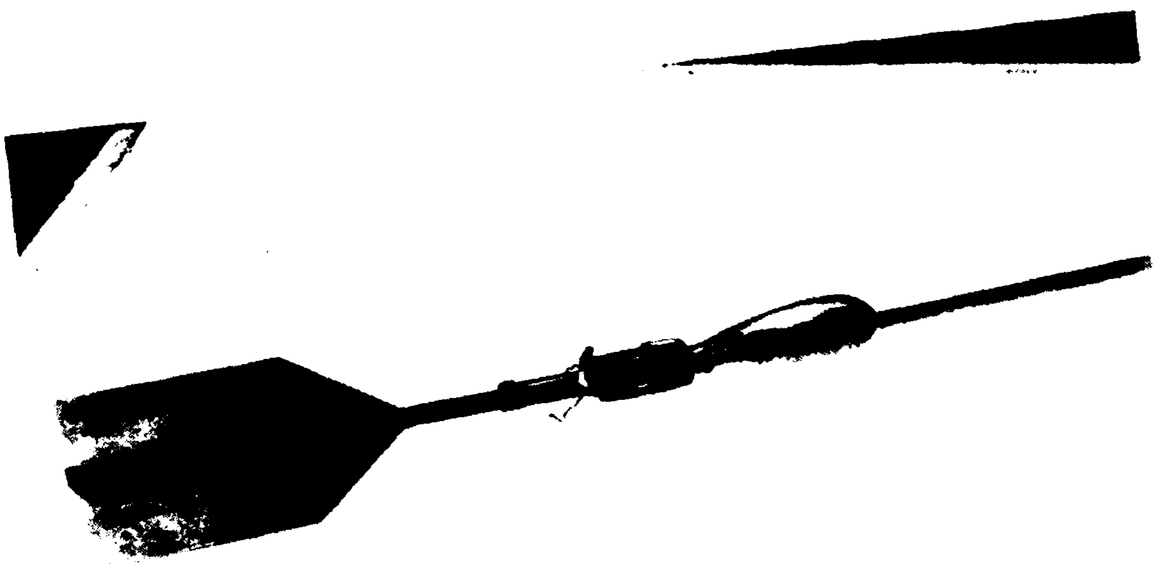
C. ARDU Report No TN AERO 67, CT4 Airtrainer - Evaluation of Pressure Error Correction Test Methods, August 1979

D. ARDU Report No TS 1638, Report No 9, Airspeed Pressure Error Correction of the Nomad N22-MK1, May 1979

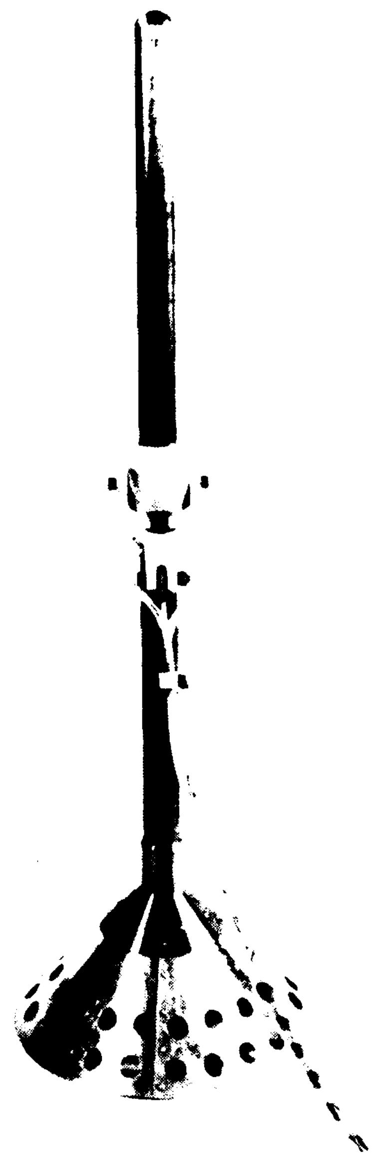
PROJECT PERSONNEL

Project Pilot: Squadron Leader D.J. Knights

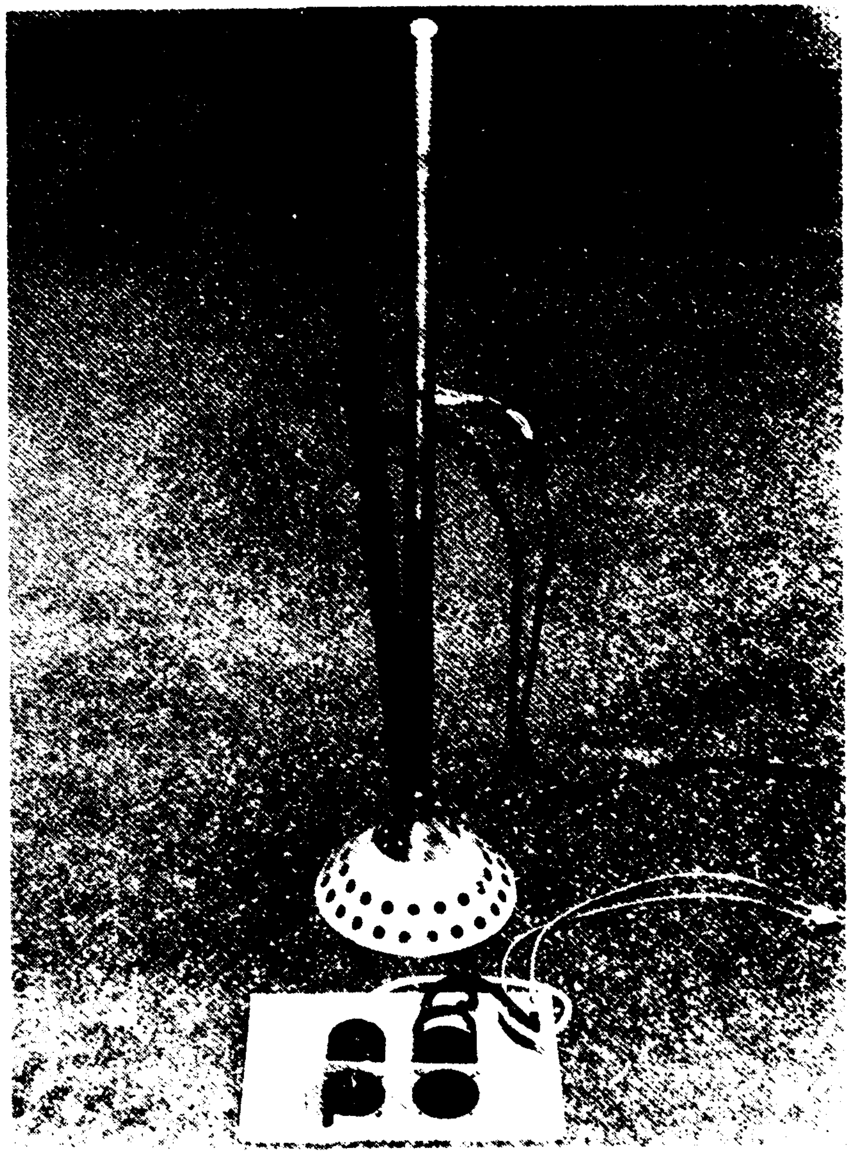
DESIGN 1 TRAILING PITOT-STATIC PROBE

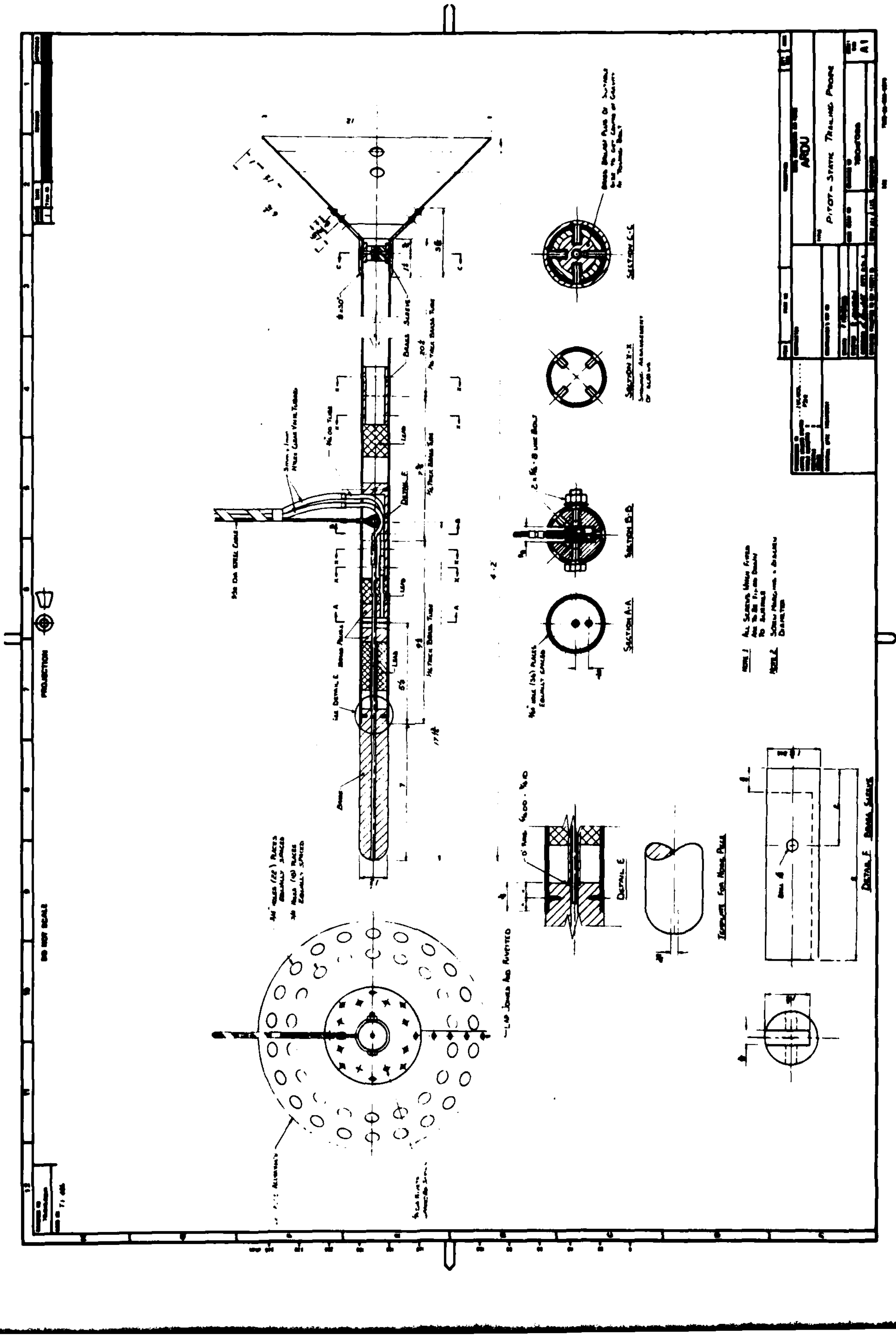


DESIGN 2 TRAILING PITOT-STATIC PROBE



DESIGN 3 TRAILING PITOT-STATIC PROBE




PITOT - STATIC TRAILING PROBE
ARDU
SECTION A-A
SECTION B-B
SECTION C-C
DETAIL E
DETAIL F
LAP JOINED AND RIVETED
PROJECTION
DO NOT SCALE

STABILITY CRITERION FOR TOWED CABLES

1. Reference B includes a simplified stability criterion for towed cables which relates the towing speed (V_T) to the speed of wave propagation (V_W) along the cable.

$$V_W = \left(\frac{T}{\mu}\right)^{1/2}$$

where T is the tension in the cable

and μ is the mass per unit length of the cable.

This reference states 'It has been found from a theoretical study of the oscillation of towed cables that oscillations travelling along the cable are amplified by aerodynamic forces when the airspeed is greater than the speed of propagation of waves along the cable'. It also states that cable oscillation in practice is not amplified rapidly until the airspeed is considerably greater than the speed of wave propagation.

2. Discussion with an engineer in Advanced Engineering Laboratory (AEL) who was involved with towing cable stability with target aircraft revealed that AEL used the criteria that $V_T \leq 1.5\ V_W$ for towing stability. This is reasonably consistent with paragraph 1.

Stability Criterion For Design 1 Tailing Pitot-Static Probe

3. The wave propagation speed (V_W) for the Design 1 trailing pitot-static probe was derived as follows:

Probe weight (W) = 5.5 lbf (24.46 N)

Drag Coefficient of Probe (C_D) = 0.2

Probe maximum diameter (d) = $1\frac{7}{8}$ inches (4.76 cm)

Probe reference area $= \pi \times (1\frac{7}{8})^2 \times 1/144 \times \frac{1}{4}$

$= 0.0192\ ft^2$ (0.00178 m)

Density of towing cable
plus plastic tubing (μ) = 0.002 slug/ft (0.0958 kg/m)

Cable tension at probe = $\left(W^2 + D^2\right)^{1/2}$ where D is the aerodynamic drag of the probe.

For this type of probe the aerodynamic drag of the probe is small compared to the weight

e.g. at 100 KIAS; Drag (D) = $C_D \times \frac{1}{2}\rho V^2 S$

$= 0.2 \times 0.5 \times .00238 \times (100 \times 1.69)^2 \times 0.0192$

= 0.13 lbf (0.58 N)

so cable tension (T) at probe approximates to W

$$\therefore V_W = \left(\frac{T}{\mu}\right)^{1/2}$$

$$= \left(\frac{5.5}{0.002}\right)^{1/2}$$

$$= 52.4 \text{ ft/s } (15.97 \text{ m/s})$$

$$= 31 \text{ knots}$$

From the criterion given in Paragraph 2, cable instability could be expected when airspeed (V_T) exceeded 1.5 x V_W

i.e. maximum V_T = 46.5 KTAS $\approx$ 45 KTAS

4. To achieve a useful towing speed of say 100 KTAS, V_W would have to be not less than 67 KTAS (i.e. 100/1.5 = 67 knots), to do this, assuming the same μ, T would have to be increased to not less than 25.5 lbf (113.4 N) or by increasing the probe drag by several orders. Both of these choices would require a complete redesign of the probe, which negated the simple approach of modifying an existing design. Another choice was to reduce the value of μ by an order which, although it may have been possible by using a single strand piano wire, would mean the cable would lose the robustness thought to be necessary for the intended use of the probe.

Stability Criterion for Design 2 Trailing Pitot-Static Probe

5. The stability criterion for the Design 2 trailing pitot-static was derived as follows:

W = 13.5 lbf (60 N)

C_D = 0.77

d = 1 ft (0.3048 m)

$$S = \frac{\pi d^2}{4} = 0.7854 \text{ ft}^2 \ (0.073 \text{ m}^2)$$

μ = 0.00404 slug/ft (0.193 kg/m)

At a towing speed of 100 KTAS or 169 ft/s

$$\frac{V_T}{V_W} = \frac{V_T}{\left(\frac{T}{\mu}\right)^{1/2}}$$

$$= \frac{V_T}{\left(\frac{(W^2 + D^2)^{1/2}}{\mu}\right)^{1/2}}$$

$$= \frac{169}{\left[\frac{(13.5^2 + (0.77 \times 0.5 \times .00238 \times 169^2 \times 0.7854)^2)^{1/2}}{0.00404}\right]^{1/2}}$$

$$= \frac{169}{\left[\frac{(13.5^2 + 20.55^2)^{\frac{1}{2}}}{.00404}\right]^{\frac{1}{2}}}$$

$$= \frac{169}{78}$$

$$= 2.17$$

This is greater than the 1.5 given in paragraph 2 indicating cable instability could occur at 100 KTAS. Repeating the above calculation for various towing speeds show that at:

a. 50 KTAS, $\frac{V_T}{V_W} = 1.41$

b. 60 KTAS, $\frac{V_T}{V_W} = 1.64$

c. 80 KTAS, $\frac{V_T}{V_W} = 1.98$

d. 100 KTAS, $\frac{V_T}{V_W} = 2.17$

From this, it appeared that instability could occur with tow speeds as low as 60 KTAS.

6. It should be noted however that, with the Design 2, the aerodynamic drag of the probe is very significant and hence V_W increases with tow speed unlike the Design 1 where V_W was virtually constant because the drag of the Design 1 was insignificant when compared to the weight. Design 2 therefore looked more promising than Design 1 and the stability criterion indicated that if the weight could be increased and the cable density reduced, towing speeds of 120 KTAS may be achievable.

Stability Criterion for Design 3 Trailing Pitot-Static Probe

7. The Design 3 probe was heavier than Design 2 and had a considerably reduced cable density achieved by using thinner cable and plastic tubes. The aft body of the probe was also considerably longer to improve the aerodynamic stability of the probe.

8. The stability criterion for Design 3 was derived as follows:

$W = 14.5$ lbf (64.5 N)

$C_D = 0.7$

$d = 1$ ft (0.3048 m)

$S = 0.7854$ ft^2 (0.073 m^2)

$\mu = 0.00166$ slug/ft (0.0795 kg/m)

At 120 KTAS, $D = 0.7 \times 0.5 \times 0.00238 \times (120 \times 1.69)^2 \times 0.7854$

$= 26.9$ lbf (119.7 N)

$$T = (W^2 + D^2)^{1/2}$$

$$= (14.5^2 + 26.9^2)^{1/2}$$

$= 30.5$ lbf (135.7 N)

$$V_W = \left(\frac{T}{\mu}\right)^{1/2}$$

$$= \left(\frac{30.5}{0.00166}\right)^{1/2}$$

$= 136$ ft/s

$= 80$ knots

$$\frac{V_T}{V_W} = \frac{120}{80} = 1.5$$

As $V_T = 1.5\ V_W$, the stability criterion indicates that Design 3 could have cable stability up to 120 KTAS

WIND TUNNEL CALIBRATION OF DESIGN 3 TRAILING PITOT-STATIC PROBE

1. The Design 3 trailing pitot-static source was calibrated in the ARL 9 ft by 7 ft low speed wind tunnel. The probe was free flown in the wind tunnel as shown in Figures 1 and 2 using the same steel suspension wire and plastic tube arrangement as was used in the flight tests.

2. The free flown probe proved to be quite stable in the tunnel up to the maximum speed tested of 117 knots with a barely detectable oscillation in pitch of less than 1^{o} and gentle small lunging motion with the probe height above the floor of the tunnel varying approximately $\pm$ 1 inch.

3. The calibration was carried out by measuring total pressure (p_t), static pressure (p_s) and dynamic pressure (p_t-p_s) directly from the probe at tunnel reference pressures corresponding to the desired speeds. The probe was then removed from the tunnel and a substandard pitot-static tube was placed in the tunnel at the position of the probe corresponding to a given tunnel reference pressure. The tunnel was then run at precisely the same tunnel reference pressure and pressures p_{to}, p_{so} and $p_{to}-p_{so}$ (where subscript o denotes the substandard pitot-static tube pressures) were recorded. Pressure errors for the trailing pitot-static probe were taken as the differences between the probe pressures and those from the substandard pitot-static tube.

4. The calibration supplied by ARL is given in Table 1 using the following notation

$$\Delta V = V - V_o$$

where ΔV is the velocity error of the trailing pitot-static source,
V is velocity derived from the trailing pitot-static source
and Vo is velocity derived from the substandard pitot-static tube.

Note: V and Vo were derived from the measurements of the dynamic pressure from the trailing pitot-static source and the substandard pitot-static probe respectively.

$\Delta V'$ is the velocity error of the trailing pitot-static source derived from the C_{p_s} and C_{p_t}

$$\frac{\Delta V'}{V_o} = (C_{p_t} - C_{p_s} + 1)^{\frac{1}{2}} - 1$$

$$C_{p_s} = \frac{p_s - p_{so}}{p_{to} - p_{so}}$$

and

$$C_{p_t} = \frac{p_t - p_{to}}{p_{to} - p_{so}}$$

where C_{p_s} and C_{p_t} are the non dimensional pressure coefficients for static and total pressures respectively.

$$C'_{p_s} = 1 - \left(\frac{\Delta V}{V_o} + 1\right)^2$$

where C'_{p_s} is the pressure coefficient for the trailing pitot-static probe derived from the measured velocity errors (ΔV) assuming no error in the probe total pressure i.e. $C_{p_t} = 0$

5. Table 1A, Column 3 shows that the velocity error for the probe is less than 1% and very close to that achieved for the ARL copy of the probe (Table 1E, Column 3). However, there is an anomaly in the values of C_{p_t} given in Table 1A, B and C. This indicates that the total pressure of the probe is up to 1.6% greater than the tunnel total pressure as recorded by the substandard pitot tube. ARL investigated this anomaly but an explanation was not found. Tests with the probe rigidly mounted in the tunnel (Table 1C) gave nearly the same value of C_{p_t} as for the free flying probe tunnel values, indicating that the anomaly was not due to the probe being free flown in the tunnel. Table 3E shows that, when the ARL copy of the Design 3 probe was calibrated, the anomaly in C_{p_t} was not evident. The velocity errors for the probe (Table 1A, Column 7) agree closely with the directly measured velocity errors (Table 1A, Column 3) suggesting that there may have been a bias error in the measurements of C_{p_s} and C_{p_t} and that this bias error cancels out when they are used to calculate the velocity error.

6. As a consequence of the anomaly discussed in Paragraph 5, values of C_{p_s} (Table 1, Column 8) were calculated from the directly measured $\frac{\Delta V}{V_0}$, assuming zero error in C_{p_t}, as this is thought to be the best estimate of the static pressure errors. Note that, in Table 1E, C_{p_s} approximately equals C_{p_s}.

7. A possible refinement of the Design 3 probe was to replace the mounting bolt with a flush fitting bolt. ARL tested this configuration and the result given in Table 1B shows only small differences to the results in Table 1A.

8. During the free flying tunnel tests the probe was photographed (example given in Figures 1 and 2). From the photographs measurements were taken of the angle of attack of the probe (θ) and the angle between the suspension wire and the longitudinal axis of the probe (γ). The results are presented in Figure 3. This shows that angle of attack is reasonably constant, between 0.8° and 0.9° nose down.

9. A tunnel result of general interest (Table 1D) is with the probe rigidly mounted and the tail cone removed. It shows, as expected, that the probe pressure errors are primarily due to the tail cone and that the static holes are reasonably located and do not give rise to any significant probe nose effects on the measured static pressure.

10. The recommended speed pressure error correction (PEC) derived from Table 1 is given in Figure 4 and is the average between the PECs for the ARDU probe and the ARL copy of the ARDU probe. The static pressure error coefficient recommended is given in Figure 5 and is the average between the results for the two probes, assuming C_{p_t} is zero.

TABLE 1 - ARL CALIBRATION DATA FOR DESIGN 3 TRAILING PITOT-STATIC PROBE

A DESIGN 3 FREE FLYING IN TUNNEL							
ARL CALIBRATION DATA					DERIVED FROM ARL CALIBRATION DATA		
V_o		$\frac{\Delta V}{V_0}$	C_{p_s}	C_{p_t}	$C_{p_t} - C_{p_s}$	$\frac{\Delta V'}{V_0} x100$	C_{p_s}
(ft/s)	(knots)	(%)				(%)	
1	2	3	4	5	6	7	8
197.9	117.2	-0.92	0.030	0.012	-0.018	-0.90	0.018
163.1	96.6	-0.93	0.029	0.011	-0.018	-0.90	0.019
119.5	70.8	-0.95	0.034	0.013	-0.021	-1.06	0.019
86.8	51.4	-0.92	0.034	0.016	-0.018	-0.90	0.018
69.8	41.3	-0.87	0.034	0.014	-0.020	-1.01	0.017
B DESIGN 3 WITH FLUSH FITTING MOUNTING BOLT, FREE FLYING IN TUNNEL							
197.8	117.1	-0.91	0.030	0.015	-0.015	-0.90	0.018
163.1	96.6	-0.89	0.030	0.013	-0.017	-0.90	0.018
119.2	70.6	-0.84	0.030	0.013	-0.017	-1.06	0.017
86.8	51.4	-1.01	0.031	0.009	-0.022	-0.90	0.020
69.8	41.3	-0.93	0.032	0.010	-0.022	-1.01	0.019
C. DESIGN 3 ON RIGID WIRE SUPPORTS IN TUNNEL							
197.5	117.0	-0.84	0.037	0.018	-0.019	-0.95	0.017
D. DESIGN 3 ON RIGID WIRE SUPPORTS IN TUNNEL - TAIL DRAG CONE REMOVED							
197.5	117.0	-0.20	0.005	0.006	0.001	0.05	0.004
E. DESIGN 3 PROBE BUILT BY ARL TO ARDU DRAWING NO 78015000 (ANNEX C) ARL CALIBRATION FREE FLYING IN TUNNEL							
199.4	118.1	-0.67	0.011	-0.002	-0.013	-0.65	0.013
164.8	97.6	-0.84	0.014	-0.003	-0.017	-0.85	0.017
120.7	71.4	-0.97	0.018	-0.001	-0.019	-0.95	0.019
86.6	51.3	-1.02	0.017	-0.003	-0.020	-1.00	0.021
69.5	41.1	-0.96	0.018	-0.001	-0.019	-0.95	0.019

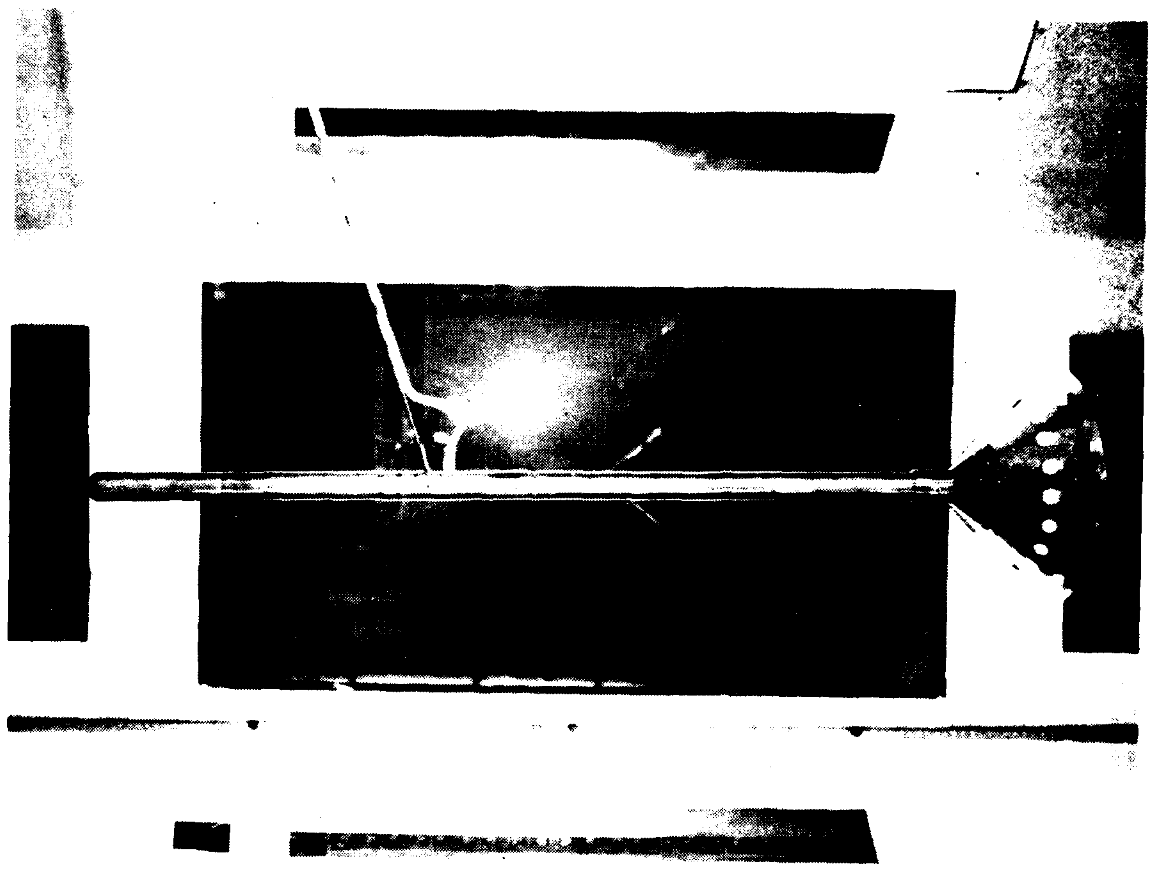


Figure 1 - Design 3 Trailing Pitot-Static Probe Free Flying in Wind Tunnel - Airspeed 51.4 Knots

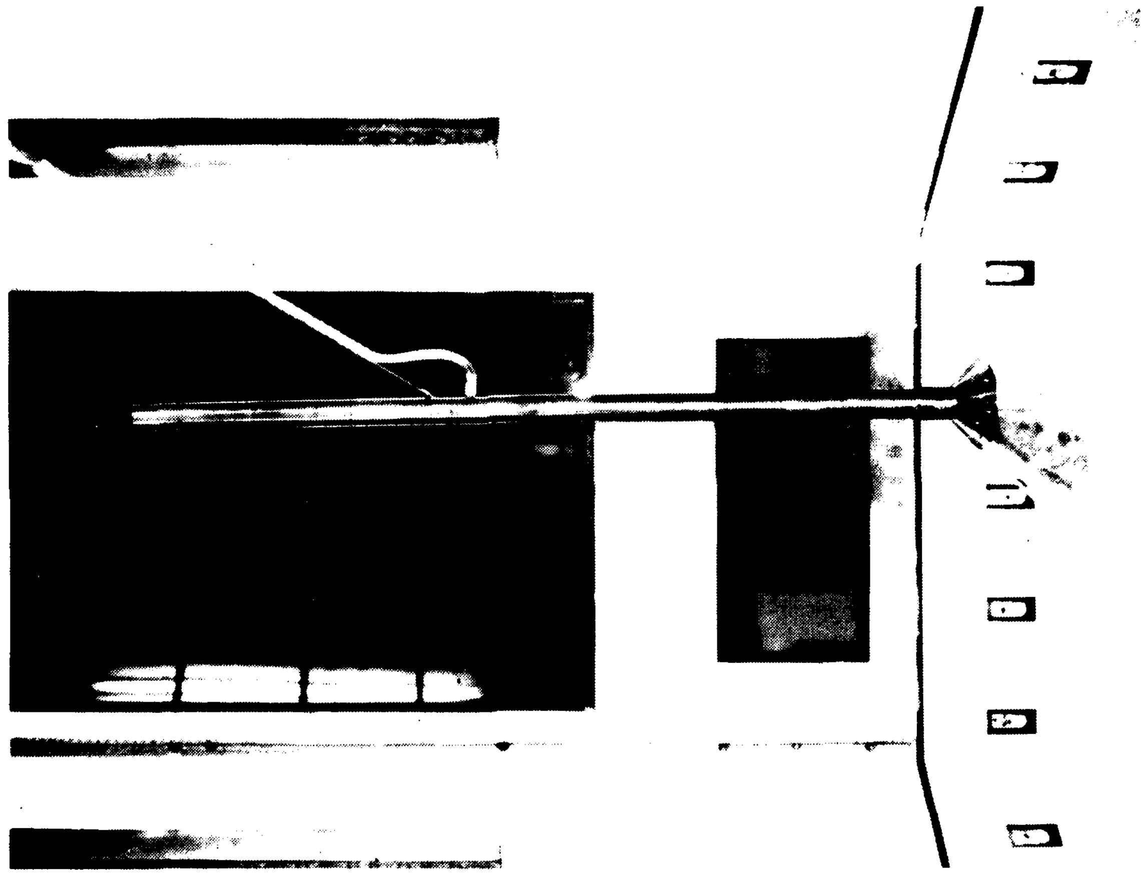
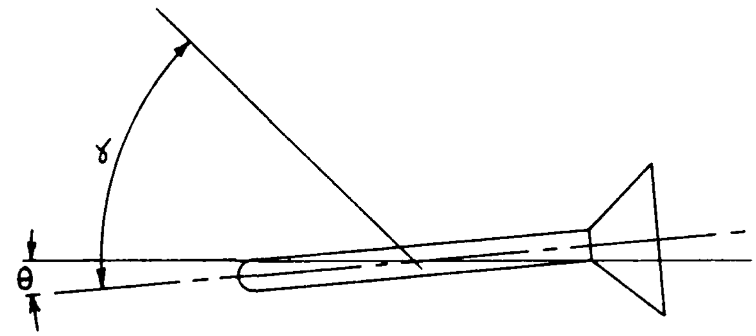


Figure 2 - Design 3 Trailing Pitot-Static Probe
Free Flying in Wind Tunnel - Airspeed 117.2 Knots



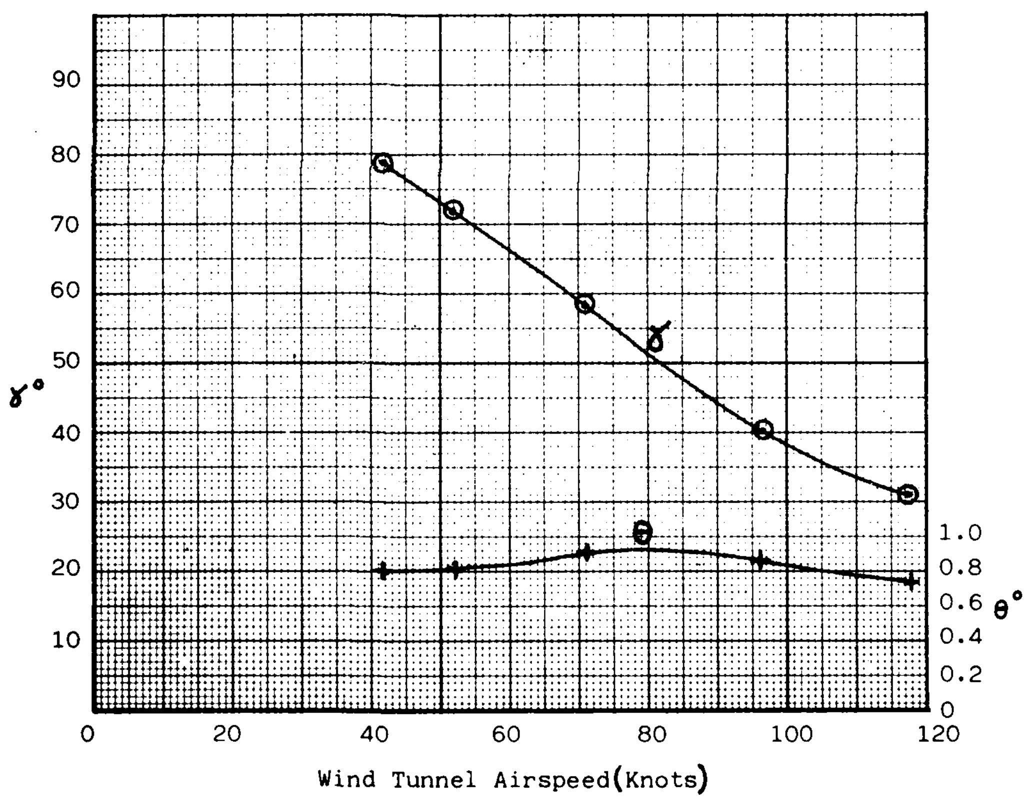


Figure 3 - Variation of Incidence (θ) and Angle Between Wire and Probe (γ) With Speed

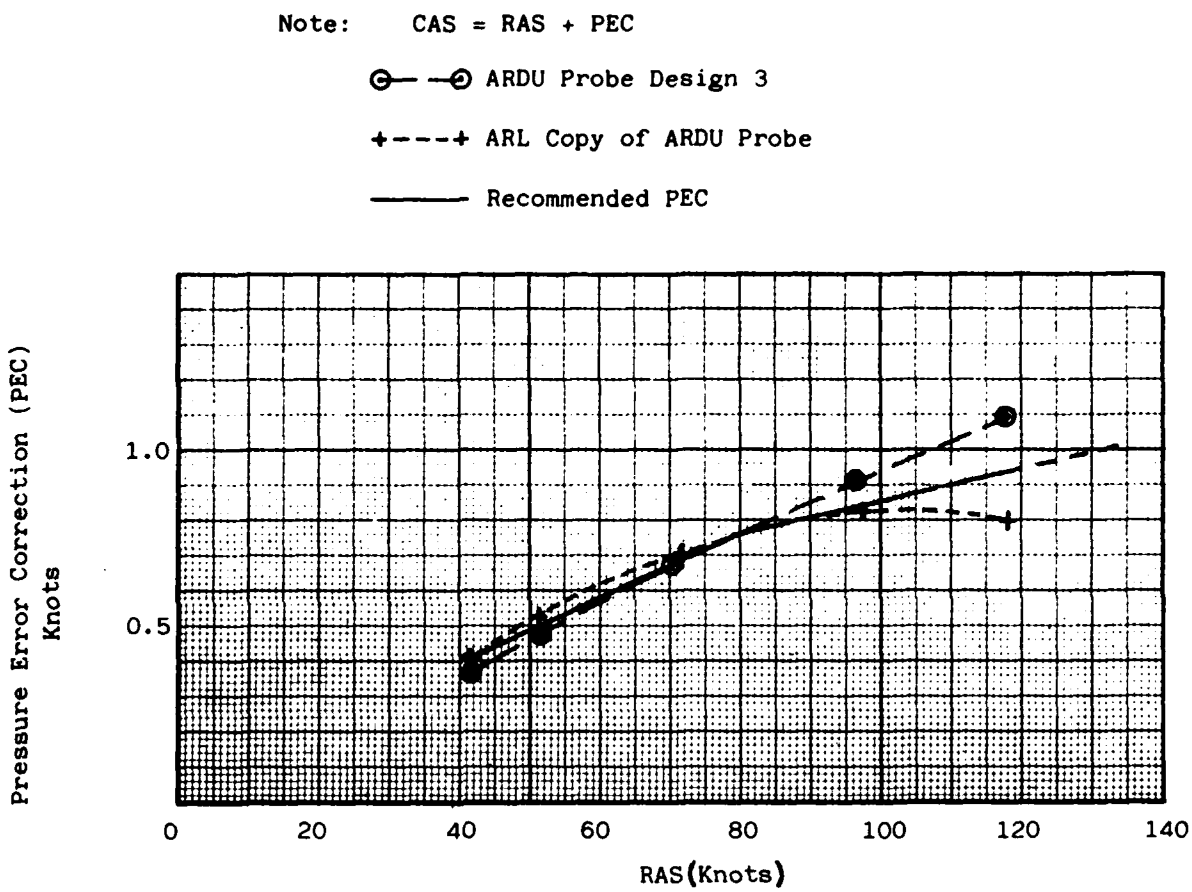


Figure 4 - Speed Pressure Error Correction (PEC)

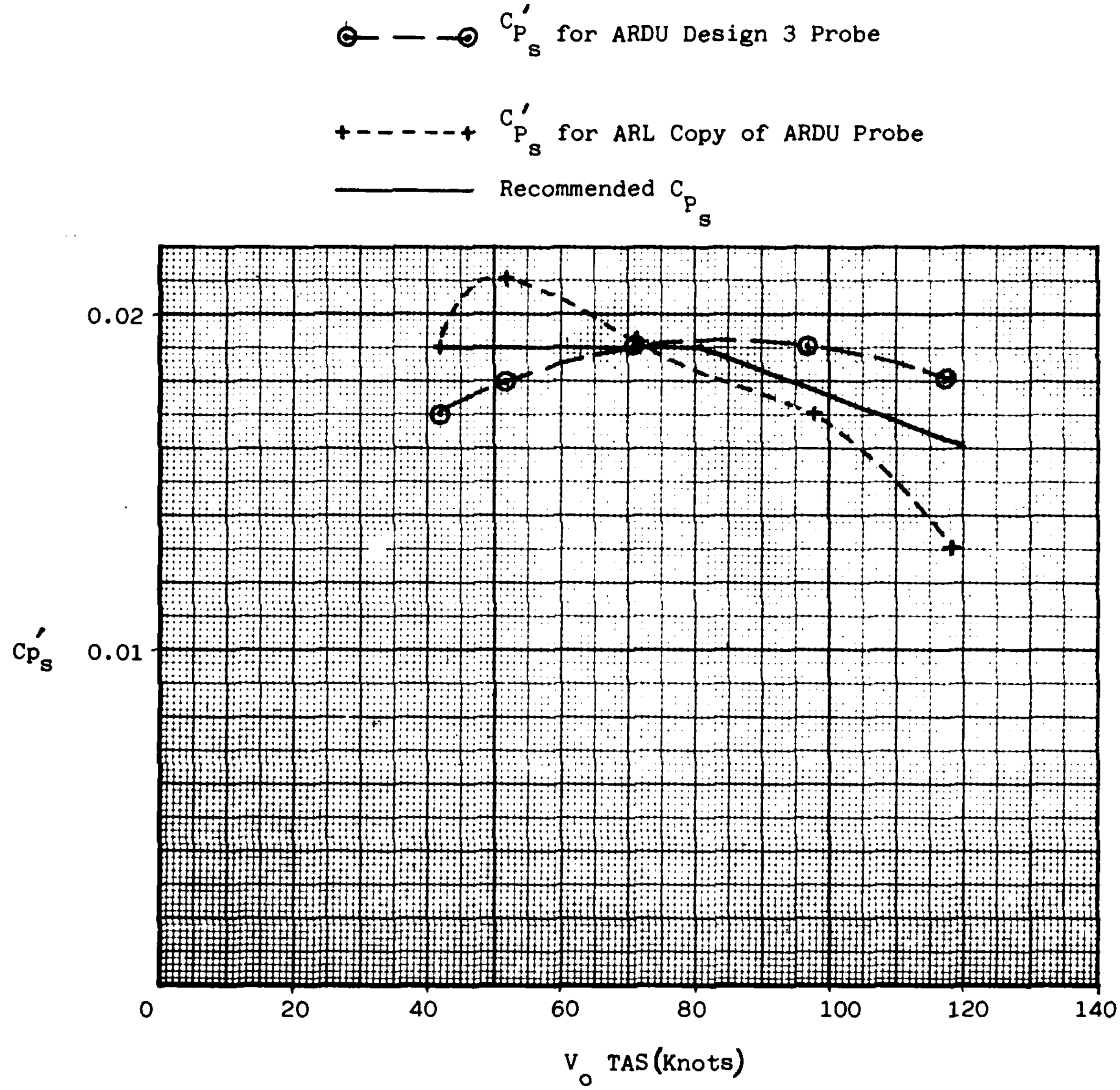


Figure 5 - Static Pressure Error Coefficient (Cp'_s)
Assuming Zero Total Pressure Error

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